of return regulation. Of the evidence presented on record, only the USTA/Christensen TFP model appropriately measures the actual LEC inputs used to produce the actual LEC output and, thus, can be relied upon as an accurate measure of TFP suitable to determine the productivity offset in the Commission's price regulation plan.

1. AT&T's Price of Capital Is Measured Incorrectly[4]

Capital is different from other inputs to production in that the users of capital are also the owners of that capital. Since there is no market transaction to reveal the price and quantity of capital, the measurement of capital requires an alternative approach. This subject has been given considerable attention in economics literature.[5] Economic theory makes it clear that the price of capital depends on (i) the firm's opportunity cost, (ii) the useful economic life of capital, (iii) the rate at which capital equipment loses or gains economic value over time, and (iv) taxes. If any of these components is not dealt with in accordance with economic theory, the resulting measure of the price of capital is flawed. Dr. Norsworthy did not measure the price of capital correctly. In the sections that follow we describe the correct way to measure the price of capital, compare it to Dr. Norsworthy's approach and show that Dr. Norsworthy's measurement of the price of capital is critically flawed.

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[4] Our presentation does not address the so-called quality adjustment embodied in the price of capital in AT&T's model. We note, however, that the quality adjustment proposed by AT&T is undocumented and no information about it was provided in any of the workpapers supplied by AT&T. The issue of AT&T's quality adjustment is fully discussed in L.R. Christensen, P.E. Schoech and M.E. Meitzen, *Total Factor Productivity Methods for Local Exchange Carrier Price Cap Plans: Reply Comments*, March 1, 1996.

[5] R. E. Hall and D. W. Jorgenson, "Tax Policy and Investment Behavior," *American Economic Review* 57 (1967) at 391-414; M. J. Harper, E. R. Berndt and D. O. Wood, "Rates of Return and Capital Aggregation Using Alternative Rental Prices," in *Technology and Capital Formation*, ed. D. W. Jorgenson and R. Landau (Cambridge, MA: MIT Press, 1989) at 331-372; D.W. Jorgenson, "Capital Theory and Investment Behavior," *American Economic Review* 53(2) (May, 1963) at 247-259; C. R. Hulten, "The Measurement of Capital," in *Fifty Years of Economic Measurement: The Jubilee of the Conference on Research in Income and Wealth*, National Bureau of Economic Research Studies in Income and Wealth, vol. 54, ed. E. R. Berndt and J. E. Triplett (Chicago and London: University of Chicago Press, 1990) at 119-152; and D. W. Jorgenson, F. M. Gollup, and B. M. Fraumeni, *Productivity and U.S. Economic Growth* (Cambridge, MA: Harvard University Press, 1987) at 122-130.

a. The Appropriate Price of Capital Includes the Firm's Opportunity Cost, Depreciation, the Effect of Economic Revaluation of Plant and Equipment, and the Effect of Taxes

Recognizing that capital transactions are not observable, conventional economic theory develops an implicit rental rate as the price of capital which is based on:

- the opportunity cost of capital held;
- the decline in efficiency of plant and equipment;
- changes in prices of plant and equipment; and,
- the cost of property and profit taxes.

The implicit rental rate formula takes the general form:[6]

$$Rental\ Price = [(P \times R) + (P \times D) - \Delta P] \times [(1 - u \times z - k) \div (1 - u)]$$

where P is an asset price deflator, R is a measure of after tax return, D is a depreciation rate, ΔP is a capital gain term, and u, z, and k represent taxes and tax credits.[7] The economic rental price has four components: (i) the opportunity cost of capital held $(P \times R)$; (ii) the decline in efficiency of plant and equipment $(P \times D)$; (iii) changes in prices of plant and equipment (ΔP); and, (iv) the cost of property and profit taxes $[(1 - u \times z - k) \div (1 - u)]$.

b. The AT&T "Performance-Based Model" Uses a Price of Capital Incorrectly Based on Making Actual Expenditures Equal to Actual Revenue

Dr. Norsworthy does not calculate the price of capital using the proper economic concepts described above. Rather, he uses an ad hoc approach in which "[t]he defining element

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[6] See L. R. Christensen and D. W. Jorgenson, "The Measurement of U.S. Real Capital Input, 1929-1967," *Review of Income and Wealth* (December 1969) at 293-320.

[7] Specifically, u, z, and k represent the corporate tax rate, the present value of normalized depreciation deductions and the effective investment tax credit rate, respectively

of that method is to focus on the actual financial performance of the LECs."[8] Dr. Norsworthy indexes the following formula to the base year (1984) and defines the price of capital as:

$$\frac{Total\ Revenue - TotalExpense + Depreciation}{GrossPlant - Depreciation\ Reserve}$$

Using the parlance of the AT&T model, this equates to:

$$\frac{NetIncome + Depreciation}{NetCapitalStock}$$

which means that Dr. Norsworthy defines the price of capital as a function of LEC accounting returns, accounting depreciation and accounting book value of plant.[9] There is no relationship between these accounting concepts and the components of an economic measure of the price of capital—i.e., the firm's opportunity cost, the useful economic life of capital or the rate at which capital losses or gains economic value over time. We can describe the flawed reasoning embodied in Dr. Norsworthy's approach using his own words.

> When the actual performance of the LECs is taken as the basis of calculation, the price of capital input that is levied on the ratepayers is determined as the gross return to capital per unit of capital input.[10]

Actual accounting performance simply does not matter in the calculation of the price at which capital can be bought and sold! Thus, the achieved accounting return to capital has no relevance in the development of capital prices. By using the actual financial performance of the LECs (the regulated books), Dr. Norsworthy's calculation relies on the LECs' accounting revenues and accounting earnings to calculate the price of capital. The critical issue in a TFP study is the economic price of capital experienced by the firm. A TFP study is concerned with measuring

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[8] Norsworthy at 19.

[9] It is interesting to note that Dr. Norsworthy's formulation of the price of capital bears no resemblance to the discussion presented in Attachment 2 of Dr. Norsworthy's Statement.

[10] Norsworthy at 19.

the efficiency with which inputs are used to produce outputs. There is no meaningful relationship between (i) how efficiently LECs produce output with given inputs (i.e., TFP) and (ii) measures of regulated accounting revenue and/or how much the regulatory accounting rules indicate companies earn on the defined rate base. In other words, the AT&T model does not measure TFP.

There are a number of obvious errors in Dr. Norsworthy's approach which we will describe in detail below.

c. Errors in the Treatment of Capital Price in the "Performance-Based Model"

There are four fundamental problems in the way Dr. Norsworthy treats capital in the AT&T model: (i) realized accounting return is not the opportunity cost of capital; (ii) accounting returns are unreliable; (iii) the *book* value of plant is not the same as the *economic* value; and, (iv) treating capital expenditure as a residual introduces errors from changes in measurement (e.g., tax law changes, regulatory depreciation changes and accounting changes).

(1) Dr. Norsworthy's Capital Prices do not Include an Appropriate Measure of Opportunity Cost

Accounting returns do not equal economic returns, and Dr. Norsworthy incorrectly relies exclusively on accounting returns. The firm's realized return should not be used as a factor to determine the opportunity cost of capital because in any given period, the firm could "realize" more or less return due to factors that have nothing whatsoever to do with the opportunity cost of capital. For example, realized earnings rise and fall due to new service introduction, call volume increases or decreases and accounting changes.

A consequence of the AT&T model's capital price measurement is that any change in measured accounting earnings will change the price of capital. This is a ridiculous outcome. In telecommunications, where large amounts of fixed investment can support a wide variety of services beyond the current service mix, there is often little or no additional investment required to provide new products. For instance, it could be the case that with little additional

cost or investment, a local exchange company could offer a new service that produces new revenue. In consequence, the firm's "actual financial performance" would be improved—measured return would increase—and according to Dr. Norsworthy's formulation, the price of capital would increase.[11]

Changes in demand will also change the price of capital as measured by AT&T. Any event which increases call volume—e.g., Mothers' Day or a blizzard—will also, according to Dr. Norsworthy, change the price of capital. Such increases in call volume require no new investment and are likely to produce more revenue than expense. Following the logic described in the previous paragraph, net income will rise and, according to Dr. Norsworthy's capital price measurement, the price of capital and the opportunity cost of capital will increase. This is simply an unacceptable result that makes no economic sense and is clear evidence that Dr. Norsworthy's measurements are based upon critically flawed reasoning.

(2) Accounting Returns are Unreliable

It is generally understood by economists that "accounting rates of return, even if properly and consistently measured, provide almost no information about economic rates of return."[12] Indeed, it is easy to see why accounting data generally produce noisy measures of economic variables (e.g., cost, profit, return). In general, LECs provide a wide variety of services so that overall LEC accounting data are aggregated over many services. Data constructed at the switch or at the distribution level for a particular service do not (and should not) reflect costs incurred at the firm level. For example, LECs have fixed costs that support all operations and that are properly ignored when determining the cost basis for pricing a particular service. The accounting cost, however, includes an allocation (on an arbitrary basis) of those

[11] This can be seen in the numerator of the AT&T model's capital price formula. The new product is more likely to increase total revenue than expense, thus net income will rise and the price of capital will increase.

[12] Fisher, Franklin M. and John J. McGowan, "On the Misuse of Accounting Rates of Return to Infer Monopoly Profits," *American Economic Review* 73(1) at 82-97.

same fixed costs to all individual lines of business and thus differs from the economic cost. The problem is well known and severe.

> Now, it should be obvious that only by the merest happenstance will the accounting rate of return on a given investment, taken as the ratio of net revenue to book value in a particular year, be equal to the economic rate of return that makes the present value of the entire net revenue stream equal to the initial capital cost.[13]

Dr. Norsworthy's model relies exclusively on accounting rates of return. Economists recognize that such measures are unreliable and provide virtually no useful information about the economic rate of return. This is further evidence that Dr. Norsworthy's calculations yield no useful information.

(3) The Book Value of Plant is Different from its Economic Value

In calculating the price of capital, Dr. Norsworthy uses a formula that bears only a superficial resemblance to the correct formula. His formula is incorrect because he substitutes *regulatory accounting values* of the relevant variables for *economic values*. In particular, Dr. Norsworthy's capital price, calculated as the ratio of accounting net income plus accounting depreciation to *net book value* is incorrect because the correct capital price is the ratio of the capital expenditures[14] to the *economic value* of the plant.

The most important fundamental difference between Dr. Norsworthy's approach and the correct formula is the fact that the book value of the plant does not equal the economic value. To illustrate this point, consider the purchase of a car. Suppose a car is bought for $20,000 at the beginning of the year and a new CD player system (which cost $1,000) is added at end of the year. How much is the car worth at the end of the year? According to regulatory accounting, which establishes the net book value, the answer is the initial price minus allowed depreciation

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[13] Fisher, *Op. Cit.* at 83 [footnote omitted].

[14] Capital expenditures are the rental price presented earlier times the economic value of the plant. Therefore, dividing capital expenditures by economic value yields the capital (rental) price.

plus the new addition. For example, if the allowed depreciation rate is 10 percent, the "book value" of the car would be $20,000 - [10% x $20,000] = $1,000 = $19,000.

The economic value is obtained by answering the question: for how much could the car be sold at the end of the year? This outcome would depend on (i) how much value the car lost, in real terms (i.e., assuming that the price of a new car hasn't changed) and (ii) how much the price level of a new car has changed. In addition, to the extent that the addition of the CD player can be passed through in the price of the used car, the value has increased accordingly. For example, if the price of new cars has increased by 4 percent and the real depreciation rate is 20 percent, the economic value of the car would be $20,000 - [20% x $20,000] + [4% x $20,000] + $1,000 = $17,800. Therefore, only if the regulatory depreciation rate just equaled the sum of the real economic depreciation rate minus the inflation rate for new car prices would the regulatory book value equal the economic value.

The example illustrates the difference between the book value and the economic value for a single period. In a productivity study, this discrepancy between book value and economic value would accumulate over the duration of the TFP study. The difference between the book value and the economic value also affects the respective estimates of annual capital expenditures. Therefore, because the capital price is the ratio of capital expenditures to economic value, Dr. Norsworthy's estimates of capital prices are biased.[15]

(4) Treating Capital as a Residual Introduces Measurement Errors

In Dr. Norsworthy's model, annual capital expenditures are the difference between revenues and non-capital expenditures. Treating capital expenditures as a residual produces two types of measurement errors. First, as discussed earlier, revenues can and do change for reasons unrelated to the price of capital, e.g., from the introduction of non capital-intensive new services. Second, measuring capital expenditures as a residual means that any measurement

[15] Similarly, because the quantity of capital is its economic value in constant dollars, using book value also biases Dr. Norsworthy's capital quantity index.

errors and/or changes in how certain quantities are measured on the cost side also show up as a spurious change in capital expenditures. At best, such measurement errors increase the variation in the measured capital prices and may even cause the measurement to be biased. For example, if a company books an expense such as the cost of an early retirement offering in a particular year, in Dr. Norsworthy's calculation, the capital expenditures for that year would be reduced for reasons totally unrelated to the price of capital itself.[16] Similarly, unless care is taken, residual measures can be influenced by factors such as changes in accounting practices and the like.

B. AT&T's Model is Riddled With Careless Mistakes

In addition to critical flaws in economic reasoning, the AT&T model is riddled with careless mistakes. Data are not consistently reported and growth rates of key variables are calculated neglecting one time period.

Even a casual inspection of Dr. Norsworthy's work reveals careless methods and undocumented data. Dr. Norsworthy presents two tables, each labeled Input Price Indices for RBOCs. One is presented as Table 5 in his Statement (Appendix A)[17] and the other is presented as Table 2 in his Statement (Appendix B).[18] Since both tables have the same title and are discussed by Dr. Norsworthy using similar language in the text of his statements both should show the same data. The data in these two tables are not all the same.[19] Moreover, neither table presents input price data which agrees with the data in Dr. Norsworthy's workpapers provided by AT&T—an error which leaves us uncertain about how Dr. Norsworthy actually arrived at

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[16] Recall that Dr. Norsworthy's measure of capital expenditures is revenue plus depreciation minus total expenses. Accordingly, increases in book expenditures for labor and material that are not passed through to revenues (which would typically be the case under price caps) show up as decreases in capital expenditures through the laws of simple arithmetic.

[17] Norsworthy at 22.

[18] *Statement of Dr. John R. Norsworthy: Responses to Issues for Comment.* Appendix B to the "Comments of AT&T" dated January 11, 1996, CC Docket No. 94-1.

[19] Table 5 shows the 1993 Capital All RBOCs index value as 0.684 and the 1989 All Inputs All RBOCs index value as 0.986. Table 2 respectively shows the same index values as 0.664 and 0.882.

his conclusions about LEC input price growth. In addition, Dr. Norsworthy selectively chose to include *only a portion* of the input price data available in his workpapers when he calculated LEC input price growth. As we discuss later, this calculation is a key part of Dr. Norsworthy's conclusion that LEC and U.S. input price growth rates differ by 2.54 percent, and it is important to understand that he has selected a period over which to make this comparison, rather than using all of the available data.

III. THE INPUT PRICE DIFFERENTIAL IS ZERO

Dr. Norsworthy concludes "unequivocally" that a point estimate of the historical input price differential should be included in the X factor for LEC price cap regulation and that the best estimate of that differential should be taken as 2.23 percent from the Bush-Uretsky study.[20] There could hardly be a statistical conclusion more equivocal than this one. In January 16, 1996 Comments, USTA, Christensen Associates and NERA showed that (i) the data used by Bush-Uretsky were *not* a consistent measure of LEC or U.S. input prices, (ii) the long-term input price growth differential is zero, and (iii) the short-term post-divestiture input price differential is consistent with a long-term input price growth differential of zero. By contrast, Dr. Norsworthy's purports to contribute to this debate by:

- recommending that the point estimate of a parameter be used irrespective of the sampling error associated with the estimate
- asserting that the relevant question is "How did movements in LEC input prices differ from input prices in the national economy?" not whether there was a significant difference in the average input price growths for the LECs and the U.S. economy, and
- presenting new input price growth measures which allegedly show that LEC input prices grew more slowly during the 1985-1994 period than BLS non-farm input prices during the 1985-1993 period.

[20] Norsworthy at 17.

We show below that Dr. Norsworthy's methodological assertions are incorrect and that his new measurements of LEC input prices also support the view that on average, the growths of LEC and U.S. input prices are the same.

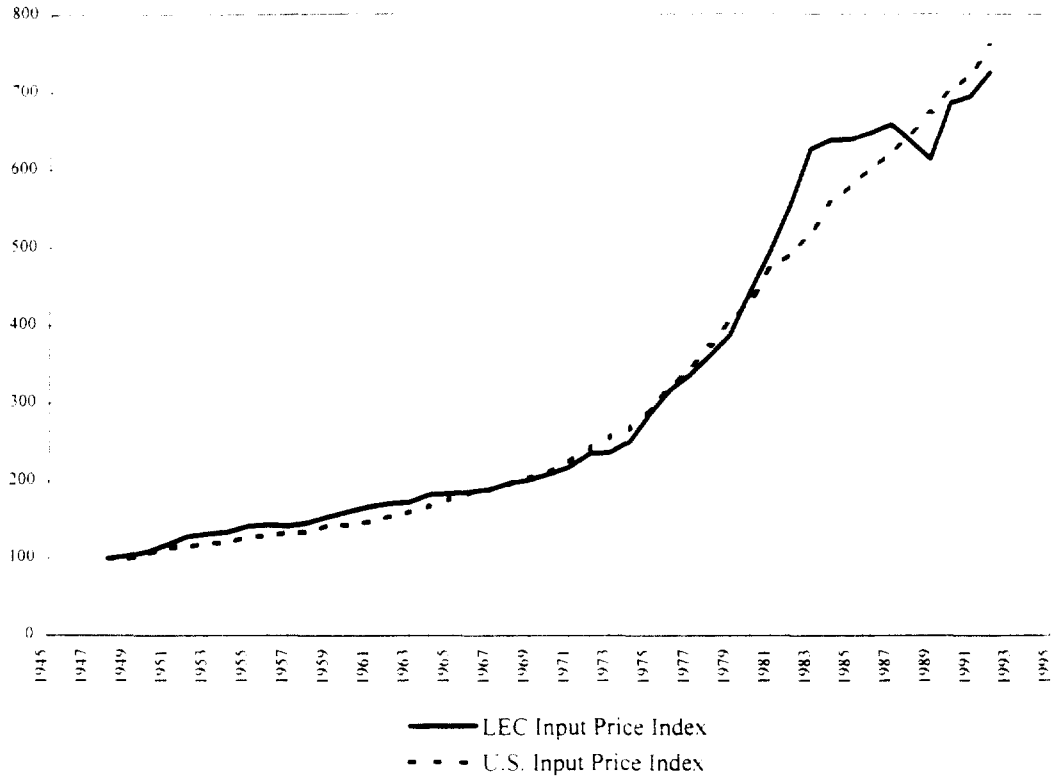
A. The Long-Term Input Price Differential Trend is Zero And There Was No Permanent Change in the Trend at Divestiture

In comments filed January 16, 1996, NERA and Christensen Associates responded to the empirical and methodological conclusions in the Bush-Uretsky study. In summary, Bush-Uretsky relied on a data set that combined LEC input prices calculated using two different methods for the 1960-1984 and 1984-1992 period. From it, they obtained a point estimate of the input price growth differential for the 1984-1992 period and a conclusion that the historical relationship between LEC and U.S. economy-wide input prices changed at divestiture. On the contrary, a careful analysis of the data shows that there is no difference between the long-run and post-divestiture input price growth differentials.

Figure 1 shows LEC and U.S. input price indices developed using the Christensen 1 data set for the 1948-1992 period.[21] The input price indices track each other very closely from 1948 to 1979. LEC input prices then grow more rapidly than U.S. input prices from 1980 to 1983, more slowly from 1983 to 1989 and more rapidly again from 1990 to 1992. Relying on a devious choice of dummy variables, and extending analytical tools beyond their capabilities, one could conclude incorrectly that the relationship between LEC and U.S. input prices changed permanently at divestiture. The evidence, however, shows that (i) the change did not begin in 1984 and (ii) the change was not permanent, reversing itself in the 1990-1992 period. The data used by the FCC and others simply do not show a permanent, one-time change in the relationship between LEC and U.S. input prices in 1984. From the evidence shown in Figure 1, it would be impossible to argue that the mean input price differential growth rate for the 1984-

[21] The Christensen 1 data set show in Figure 1 above and the Christensen 2 data set used by Bush-Uretsky, are both fully described in Taylor, Tardiff and Zarkadas, *Op. Cit.*, and in the *Christensen Input Price Affidavit*, filed with the FCC on February 1, 1995.

Figure 1: LEC and U.S. Input Price Indices from 1948-1992



1990 period would be the best forecast of future input price differential growth rates. On the contrary, using the Christensen 1 data set, the evidence suggests that a one-time deviation from historical norms has reversed itself and that U.S. and LEC input price changes should now again approximately equal one another. If there was a shift, the data utilized by the Commission demonstrates that it was temporary and is now over.[22]

[22] It is noteworthy that the Bush-Uretsky results and Norsworthy's conclusion—that their study "established the case for applying an input price differential in computing the X-Factor in the LEC price cap regulation" (Norsworthy at 17)—are based on LEC input price data developed under a methodology that has subsequently been modified to conform to the criteria established by the Commission in the Fourth FNPRM. See L.R. Christensen, P.E. Schoech and M.E. Meitzen, *Total Factor Productivity Methods for Local Exchange Carrier Price Cap Plans Reply Comments*, March 1, 1996 for a current description of how LEC input prices are calculated. While NERA points out the errors with the past analysis of Norsworthy, Bush-Uretsky and others, the analysis of the input price issues should be based on data derived from the Christensen Simplified TFP (continued...)

B. NERA Did Not "Assume" that LEC and U.S. Economy Input Prices Move in the Same Way

Dr. Norsworthy claims that the "relevant" statistical question is:

> How did movements in LEC input prices differ from input prices in the national economy?[23]

Norsworthy claims that NERA posed a different question:

> Can we reject the hypothesis that *input price movements are the same* for LECs and for the national economy?[24]

The latter Norsworthy quote is a poorly phrased version of the question that NERA actually did pose, "Can we reject the hypothesis that the mean input price growth is the same for the LECs and the U.S. economy?" Even that question, however, has nothing whatsoever to do with the various assumptions that Dr. Norsworthy erroneously ascribes to NERA's analysis. According to Dr. Norsworthy, NERA somehow rigged the analysis to (i) "assume" LEC and U.S. input prices were the same:

> [t]hat is, *if we assume* that LEC input prices and U.S. economy-wide input prices move in the same way, *and if we assume* that the annual price movements in each series are random samples taken independently of each other and independently in time, is there statistical evidence that forces us to conclude that the two sets of price changes move differently?[25]

(...continued)

model presented in Attachment B of USTA's January 16, 1996 Comments, which conforms to the Commission's criteria.

[23] Norsworthy at 6. Presumably Dr. Norsworthy means to ask "How did movements in LEC input prices differ from [movements in] input prices in the national economy?" As stated, Dr. Norsworthy's "relevant" question is meaningless because it literally compares movements in LEC input prices with levels of input prices in the U.S. economy.

[24] Norsworthy at 8.

[25] Norsworthy at 8-9.

and then (ii) used a test in such a way as to force the conclusion that they wanted: "NERA and USTA create a bias in a direction that most favors the LECs."[26]

This claim is absurd. First, NERA does *not* assume that "LEC input prices and U.S. economy-wide input prices move in the same way" or even that they have the same mean growth rates. Rather, NERA relied upon the data and a conventional hypothesis test to resolve the question: "Should we treat LEC and U.S. input price growths as observations from distributions having the same average growth?" The purpose of such a hypothesis test is:

> to permit an inference from what is known (the characteristics of the sample) to what is unknown (the characteristics of the universe), thus giving rise to the term "statistical inference."[27]

If one were to accept the Christensen 1 data set as an accurate set of observations about the input inflation differential, there is little dispute about the sample (i.e., the point estimates of the input price growth differential). However, to set a productivity offset for future periods, it is not enough to know what the sample input price growth differential was. We need to use the observed sample information to infer what the input price differential is likely to be in the future. We do this by using the current sample information to infer the characteristics of the population from which the sample was drawn.

It is a complete statistical fallacy to use a point estimate of a parameter as if it were the true value of the parameter irrespective of the sampling error of the estimate. That is exactly the fallacy that Dr. Norsworthy commits in using his sample's point estimate of the input price growth differential without taking into account its sampling error.

Thus, Dr. Norsworthy claims that:

> the USTA position is that, because the zero value falls within the confidence interval, the difference of 2.2 percent is not significant. *But the USTA position is based on a curious argument, because the*

[26] Norsworthy at 9.

[27] D.C. Baldus and J.W.L. Cole, *Statistical Proof of Discrimination* (New York: McGraw-Hill, 1980) at 305.

> *measured difference is not significantly different from any other value with the confidence interval.* Specifically, a value of 4.4 percent is just as likely as zero for the input price differential, and 4.3 percent is *more* likely. To deal with this uncertainty, statisticians and econometricians use the most likely value in the interval as the point estimate of the variable...[28]

Again, no one disputes that the point estimate of the average input price differential from the Christensen 1 sample is not precisely zero. What is vigorously disputed is the notion that any competent statistician, or econometrician or policy analyst would ignore sampling error in the use to which the parameter estimate was put. Even Dr. Norsworthy acknowledges this simple fact in his regression analyses in his Table 17 where he distinguishes between models in which the relationship between TFP growth and service quality is "significant" and those in which it is "insignificant." While the point estimates of the coefficients of these models are whatever they are, Dr. Norsworthy correctly treated those that were "significant" (i.e., those for which zero does not fall inside a 95 percent confidence interval) differently from those for which zero does fall inside a standard confidence interval. Courts do not simply take point estimates of parameters without consideration of their associated sampling error. In a grand jury discrimination case, the U.S. Supreme Court found that

> if the difference between the expected value and the observed number is greater than two or three standard deviations, the hypothesis that the jury drawing was random would be suspect to a social scientist[29]

and this rule of thumb was later elevated to a general rule, as the Supreme Court noted in *Hazelwood School District v. United States* that a disparity of slightly less than two standard deviations was not "suspect" in the context of an employment discrimination case.[30] Similarly,

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[28] Norsworthy at 13.

[29] *Castaneda v. Partida*, 430 U.S., 1977 at 496.

[30] *Hazelwood School District v. United States*, 433 U.S. 299, 1977. Cited in D.H. Kaye, "Statistical Significance and the Burden of Persuasion," *Law and Contemporary Problems* 46 (1983) at 14-23.

state regulatory bodies have treated demand response to a price change differently depending on whether the point estimate of the price elasticity of demand was statistically significant.

Second, contrary to Dr. Norsworthy's assertion, NERA did not "create a bias in a direction that most favors the LECs."[31] Dr. Norsworthy claims that the data are characterized by what statisticians call "autocorrelation" so that NERA's analysis is more likely to conclude that average LEC and U.S. input price growth rates are the same. This is simply wrong. If the data exhibited autocorrelation, it would be *more difficult*, not easier, for NERA to conclude that there is no statistical difference between LEC and U.S. input price changes.[32] In other words, NERA's t-tests would be conservative—they would be biased in the direction of finding significant differences between LEC and U.S. input price growths when no difference was present.[33] In addition, NERA's t-tests explicitly account for the (likely) difference in variances between LEC and U.S. input price growths. Thus, Dr. Norsworthy's criticism is not valid.

C. The Chi-Square Test is Inappropriate

Dr. Norsworthy asserts that

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[31] Norsworthy at 9.

[32] The t-tests that statisticians use to test whether two samples come from distributions having the same mean are known to be (i) robust to the failure of stochastic assumptions, and (ii) conservative with respect to autocorrelation (sometimes called serial dependence). Simply put, this means that if data are erroneously assumed to represent "random samples taken independently of each other and independently in time" (Norsworthy at 8) it would be more difficult, not easier for NERA to conclude that there is no statistical difference between LEC and U.S. input price changes. For disturbances that are positively autocorrelated (which means that they are not random samples independent of time), it is generally true that conventional estimators of the variance of a sample mean will underestimate that variance, so that the calculated significance level of a conventional t-statistic would *overstate* the true significance of that statistic, which depends on the extent of autocorrelation.

[33] See, e.g., Judge, Griffiths, Hill, Lutkepohl and Lee, *The Theory and Practice of Econometrics*, 2nd edition, (New York: John Wiley & Sons) 1985 at 281-282. Primary references include D.F. Nichols and A.R. Pagan, "Specification of the Disturbance for Efficient Estimation - An Extended Analysis," *Econometrica* 45 (1977) at 211-217, H.D. Vinod, "Effects of ARMA Errors on the Significance Tests for Regression Coefficients," *Journal of the American Statistical Association* 71(356) (1976), at 929-933, and J.F. Kiviet, "Effects of ARMA Errors on Tests for Regression Coefficients," *Journal of the American Statistical Association* 75(370) (1980) at 353-358.

> [t]he correct way to assess whether the two series are the same is to compare them directly. When USTA proposes using the movements in the U.S. input price index to represent or be equivalent to movements in the LEC input price index, *it is proposing that series are the same*...A chi-squared test compares the two series (of price changes in this case) and gives the probability that the series are the same.[34]

This claim is absurd; USTA makes no such assumption, nor should the FCC. Rather, USTA uses the data to determine whether the average of the LEC and U.S. input price changes are different, not to determine whether the distribution of individual annual observations in the two are different (Norsworthy's recommended test). Thus, the fact that the data reject Norsworthy's hypothesis has no bearing on the policy issue in this case.

1. The Chi-Square Test Examines an Irrelevant Hypothesis

We are not trying to determine whether, in general, the individual annual movements of LEC and U.S. input prices are the same or different. For setting a future productivity target, the appropriate question is much more narrow. What the regulator requires is an accurate estimate of the future average input price growth differential.[35] For the purpose at hand, what matters is whether LECs are likely to be advantaged on average or disadvantaged on average relative to other firms in the U.S. economy with respect to the growth of the prices they pay for inputs. The issue is thus whether the average growth rates will differ; not as Dr. Norsworthy misguidedly tests, whether the distributions of growth rates differ in other esoteric ways.

Thus, Dr. Norsworthy's Chi-Square tests are utterly pointless. They test the hypotheses that in each period LEC and U.S. input price changes are drawn from the same distribution. They do not test the relevant hypothesis that—whatever distributions gave rise to LEC and U.S. input price changes—the LEC and U.S. input price changes have the same average. Indeed,

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[34] Norsworthy at 9.

[35] Dr. Norsworthy incorrectly inquires into whether the variance, kurtosis or other higher-order moments of the distributions of LEC and U.S. input price growths are the same or whether—in general—the cumulative probability distribution functions of the two random variables are the same or are different.

because LEC input prices are a small subset of U.S. economy-wide input prices, we already know that the *variance* of LEC input prices may well be different than the variance of U.S. input prices, irrespective of their averages. The fallacy of Norsworthy's approach is evident from the fact that this difference in variances—by itself—would cause Dr. Norsworthy's Chi-Square tests to reject the hypothesis that the distributions were the same even if the averages were absolutely identical.

2. A Moving Average of Input Price Differentials Does Not Solve the Problem

Dr. Norsworthy observes that using a three-year moving average of the input price growth differential would "reduce the uncertainty associated with the input price differential even further."[36] As evidence, he cites the reduction in the range of the confidence intervals from annual observations (Norsworthy, Table 3) to three-year average observations (Norsworthy, Table 4). The problem remains, however, that the original data are consistent with an input price growth differential of zero measured over any period, and moving averages cannot escape this fact. Zero generaliy lies within the confidence bands sketched in both of Norsworthy's Figures 1 and 2, so that in all years but one, a three year moving average of the measured input price growth differentials would differ from zero by only sampling error. Indeed, over the 1985-1992 period for which Dr. Norsworthy presents calculations, the input price growth differential would be positive—LEC input prices grow more than U.S. input prices—for every year except 1992.[37] It is the negative value in 1992 that Dr. Norsworthy would selectively propose as a differential for the price cap formula.

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[36] Norsworthy at 14.

[37] A positive input price growth differential implies that LEC input prices were growing faster than U.S. input prices and that the appropriate productivity offset in a price cap plan would be smaller than the TFP growth differential.

3. Changes in LEC Input Prices From The "Performance-Based Model" are not Different From Changes in U.S. Economy-wide Input Prices

Dr. Norsworthy places on the record a new measure of the LEC-U.S. input price growth differential based on his own measures of LEC input prices and some unspecified measures of U.S. non-farm private business input prices.[38] While there are serious problems with the accuracy (and, indeed, the meaning) of his capital price series, which are described above, we observe here that use of these new data would not change the fundamental conclusion that LEC and U.S. input prices grew at the same rate in every period.

First, the point estimate that Dr. Norsworthy calculates is incorrect. In Norsworthy, Table 5, he subtracts the average growth rate of the prices of RBOC inputs (Dr. Norsworthy uses "RBOC" in place of "LEC") from that of U.S. non-farm business inputs and concludes that "the best point estimate of the input price differential for 1985-1994 is 2.54 percent per year."[39] However, errors have been made at both the beginning and end of the period. According to Dr. Norsworthy's workpapers, his RBOC input price series begins in 1984 and ends in 1994, so that ten annual changes are calculated, not the nine annual changes that are presented in Norsworthy, Table 5. The missing input price change (from 1984 to 1985) is 13.4 percent; including this value increases the average growth of RBOC input prices over the period from the 0.46 percent reported in Table 5 to 1.76 percent (for the 1984-1994 period).[40] For 1994, Dr. Norsworthy "extrapolates" the 1985-1993 growth rate for non-farm private business input prices to 1994 which enables him to include his flawed and incorrectly low 1994 growth estimate for RBOC input prices in his comparison. Ignoring the flaws that have been demonstrated here and elsewhere in Dr. Norsworthy's data, and using all the available data he presented, a very different point estimate emerges: according to Dr. Norsworthy's calculations, RBOC input prices grew at about 1.76 percent (1984-1994) while U.S. non-farm private

[38] Dr. Norsworthy's report and supporting workpapers give no indication as to the source of this data.

[39] Norsworthy at 21.

[40] This is an increase of 1.30 percentage points.

business input prices grew about 3.0 percent (1985-1993). Since the U.S. input price series used by Christensen shows almost identical growth for the three periods in question (1984-1993, 1985-1993 and 1984-1994),[41] it is fairly safe to conclude that the point estimate of the input price growth differential in Dr. Norsworthy's study averages about 1.24 percent over the 1984-1994 period, less than half of the claimed 2.54 percent.

Moreover, the RBOC input price calculation in Table 5 includes Dr. Norsworthy's undocumented quality adjustments to the price of capital. Regardless of the flaws that plague these adjustments, they are certainly not publicly available: the only citation in the study is to a Rensselaer Polytechnic Institute Working Paper apparently written over three years ago—indicating that the data would now be over three years out of date—and never published and not verifiable. If those undocumented adjustments are backed out of the calculation, the average RBOC input price growth reported in Table 5 (for the 1986-1994 period) would be 1.49 percent instead of 0.46 percent; if the 1984-85 growth rate were included in the average, Dr. Norsworthy's measure of RBOC input prices would have grown at 2.72 percent per year, compared with a non-farm private business input price growth rate of 3.0 percent. Thus, ignoring Dr. Norsworthy's unverifiable quality adjustments, the sample point average LEC and U.S. economy input price differential is 0.28.

Second, even using Dr. Norsworthy's careful editing of the sample period, the claimed 2.54 percent input price growth differential is not different from zero at conventional levels of significance. Using Dr. Norsworthy's data from 1985 to 1992 (the longest period of actual data in his study), the difference between the input price growth rates for U.S. non-farm private businesses and the RBOCs averages 2.6 percent but is small relative to its standard error. See Table 1.

[41] Annual growth rates for these periods are 3.95, 3.94 and 3.95 percent respectively.

Table 1: Analysis of Dr. Norsworthy's Data for RBOC and U.S. Input Price Data

	Input Price Changes	Input Price Changes
Year	U.S. Non-Farm Business[2]	All RBOCs[1]
1985		13.4%
1986	2.9%	5.4%
1987	2.5%	-0.3%
1988	3.7%	-6.5%
1989	3.0%	0.7%
1990	3.3%	-4.2%
1991	2.1%	1.0%
1992	3.0%	1.8%
Mean[3]	2.9%	1.4%
Variance[3]	0.0%	0.4%

t-Test: Independent Sample Assuming Unequal Variances (ignoring the 1984 to 1985 change)

	U.S. Non-Farm Business	All RBOCs
Mean[4]	2.9%	-0.3%
Variance[4]	0.0%	0.2%
Observations	7	7
Hypothesized Mean Difference	0	
df	6	
t Stat	2.16	
P(T<=t) two-tail	0.0745	
t Critical two-tail	2.45	

(1) Data found in the workpapers corresponding with the *Statement of Dr. John R. Norsworthy: Analysis of the TFP Methods for Measuring The X-Factor of the Local Exchange Carriers' Interstate Access Services,* Appendix A to the "Comments of AT&T" in CC Docket No. 94-1, dated January 11, 1996 and corresponding workpapers provided on disk.

(2) Rate of change calculated using data found in the workpapers corresponding with the *Statement of Dr. John R. Norsworthy: Analysis of the TFP Methods for Measuring The X-Factor of the Local Exchange Carriers' Interstate Access Services,* Appendix A to the "Comments of AT&T" in CC Docket No. 94-1, dated January 11, 1996 and corresponding workpapers provided on disk.

(3) RBOC mean and variance calculated including 1985 change.

(4) RBOC mean and variance calculated excluding 1985 change.

IV. REVENUE WEIGHTS ARE AN APPROPRIATE MEANS TO DEVELOP AGGREGATE OUTPUT IN THE LEC TFP STUDY

Dr. Norsworthy opines that:

> the economic theory of production shows that the correct weights to use for this purpose are **marginal cost weights**...[and] [i]n principle, there is little disagreement on this issue.[42]

There is little disagreement on this issue; however, Dr. Norsworthy is wrong. The proper weights for combining output growth rates to measure the growth rate of aggregate output for a price cap plan are revenue weights.[43] Both Christensen Associates and NERA have provided detailed explanations of why revenue weights should be used to measure total output when establishing a TFP benchmark.[44]

The annual price cap adjustment formula is designed so that if the firm exceeds industry average productivity growth (its productivity target), its earnings will increase, and if it falls short of industry average productivity growth, its earnings will decline. It is easy to show that the measure of productivity which accommodates this result is one which uses revenue weights for output and expenditure weights for inputs.

We want to find that value of X (the productivity target) which—if the firm attains such productivity growth—just permits revenue to grow at the same rate as costs. Suppose the firm has N outputs $(Q_i, i = 1, \ldots, N)$ and M inputs $(R_j, j = 1, \ldots, M)$ and that total revenue is given by

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[42] Norsworthy at 84 [footnote omitted].

[43] See, e.g., John E. Kwoka, "Productivity and Price Caps in Telecommunications," in Michael E. Einhorn, *Price Caps and Incentive Regulation in Telecommunications*, Boston: Kluwer Academic Publishers (1991) at 80. The issue was also discussed by Christensen, Schoech and Meitzen, *Productivity of the Local Operating Telephone Companies Subject to Price Cap Regulation*, filed as Attachment 6 to the United States Telephone Association "Comments" dated May 3, 1994.

[44] See the reports by Christensen Associates, *Productivity of the Local Operating Telephone Companies Subject to Price Cap Regulation*, and National Economic Research Associates, Inc., *Economic Performance of the LEC Price Cap Plan*, Attachment 6 and Attachment 5 respectively to the United States Telephone Association "Comments" dated May 1994

$\sum_{i=1}^{N} p_i Q_i$ and total cost is given by $\sum_{j=1}^{M} w_j R_j$ where p_i and w_j denote output and input prices respectively.

Revenues and costs grow at the same rate when:

$$\sum_{i=1}^{N} \dot{p}_i Q_i + \sum_{i=1}^{N} p_i \dot{Q}_i = \sum_{j=1}^{M} \dot{w}_j R_j + \sum_{j=1}^{M} w_j \dot{R}_j .$$

where a dot (a derivative with respect to time) indicates growth over time. Dividing both sides of the equation by the value of output or expenditure ($REV = \sum_i p_i Q_i$ or $E = \sum_j w_j R_j$), we obtain:

$$\Sigma \dot{p}_i \left(\frac{Q_i}{REV} \right) + \Sigma \dot{Q}_i \left(\frac{p_i}{REV} \right) = \Sigma \dot{w}_j \left(\frac{R_j}{E} \right) + \Sigma \dot{R}_j \left(\frac{w_j}{E} \right),$$

where REV and E denote revenue and expenditure. If $RevShr_i$ denotes the revenue share of output i and $ExpSh_j$ denotes the expenditure share of input j. then:

$$\sum_i RevShr_i \, d p_i = \sum_j ExpShr_j \, d w_j - [\sum_i RevShr_i \, dQ_i - \sum_j ExpShr_j \, d R_j],$$

where d denotes a percentage growth rate: $d p_i = \dot{p}_i / p_i$. The first term in the preceding equation is the revenue-weighted average of the rates of growth of output prices, and the second is the expenditure-weighted average of the rates of growth of input prices. The term in brackets is the difference between weighted averages of the rates of growth of outputs and inputs and is thus a measure of the growth in TFP. Rewriting the equation for clarity, we see that:

$$dp = dw - dTFP .$$

In words, the theory underlying the LEC annual price cap adjustment formula implies that the rate of growth of a revenue-weighted output price index is equal to the rate of growth of an expenditure-weighted input price index minus the change in total factor productivity

measured using revenue weights for aggregate output growth. This equation demonstrates that total factor productivity (measured using revenue weights to calculate the growth rate of aggregate output) is the appropriate foundation for a productivity offset in the price cap plan: if the plan begins with revenues that match costs—and if the firm attains its productivity goal—then the firm's revenues will continue to move with its costs.

Intuitively, using marginal cost weights to combine growth rates of individual outputs is incorrect in this context because it fails to account for the fact that the growth of outputs which are sold for a high margin (price less marginal cost) contribute more towards revenue growth than the growth of low-margin outputs. This fact is irrelevant for other analyses of productivity growth where one is explicitly trying to measure a shift in the cost or production function, and obtaining high-valued output for the same physical inputs does not necessarily constitute an increase in productivity. Such is not the case here, however.

V. CONCLUSION

We have responded to three claims made by Dr. Norsworthy on behalf of AT&T regarding an appropriate productivity offset for the LEC price cap plan. First, and most importantly, Dr. Norsworthy's so-called "Performance-Based-Model" measures the price of capital residually, adjusting that price to equate revenues and costs, so that the model does not measure total factor productivity growth as that concept is understood in economics. Like AT&T's discredited "Historical Revenue Model," the "Performance-Based-Model" ties the price cap productivity offset to LEC *accounting* returns, effectively reimposing rate of return regulation.

Secondly, the difference between the rates of growth of LEC and U.S. input prices is zero in the long run, and there is no evidence on the record to show that the difference differs from zero in any short run period. In contrast to Dr. Norsworthy's claims, the Commission seeks to set a forward-looking productivity target, and the variability of point estimates of the input price growth differential is important information in forecasting future values of that differential. Even using Dr. Norsworthy's newly-developed RBOC input price changes, the

appropriate statistical tests show no difference in the average productivity differential between Dr. Norsworthy's short run period and the long run. In fact, while LEC input prices grew more slowly than U.S. input prices in the years immediately following divestiture, they grew *faster* in the most recent years. Thus, the forecast of a zero input price growth differential is conservative in this light.

Thirdly, in contrast to Dr. Norsworthy's claims, the proper weights for combining output growth rates to measure the growth rate of aggregate output *for a price cap plan* are revenue weights. The purpose of the productivity target in a price cap plan is so that revenue changes will track cost changes when the LEC meets the expected productivity target. Economic theory demonstrates that a productivity study that combines output quantities with revenue weights satisfies this objective, and Dr. Norsworthy is wrong in asserting that only marginal cost weights are appropriate.

In short, there is little useful information in Dr. Norsworthy's submissions. While his productivity calculations are new, they are based on an idiosyncratic notion of the price and quantity of capital, and one cannot directly translate his results into a conventional measure of total factor productivity growth. Notwithstanding Dr. Norsworthy's other claims, the best estimates of LEC historical productivity growth are those calculated by Christensen Associates, and the data continue to show that the average short-term historical input price differential is consistent with its long term average value of zero.

ATTACHMENT C

Affidavit of Dr. James H. Vander Weide in Support of Reply Comments of the United States Telephone Association

James H. Vander Weide

James H. Vander Weide Co.

USTA Reply Comments 3/1/96